.. H

# REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-02-

0087



**1. REPORT DATE** *(DD-MM-YYYY)*
02-19-02

**2. REPORT DATE**
Final Technical Report

**3. DATES COVERED** *(From - To)*
04/01/00 - 07/31/01

**4. TITLE AND SUBTITLE**
Radiation Sources for Total-Dose Testing of Electronics

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**
F49620-00-1-0238

**5c. PROGRAM ELEMENT NUMBER**

**5d. PROJECT NUMBER**
3484/US

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**6. AUTHOR(S)**
Professor Ronald D. Schrimpf

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Vanderbilt University
Division of Sponsored Research
512 Kirkland Hall
Nashville, TN 37240

**8. PERFORMING ORGANIZATION REPORT NUMBER**
4-22-421-4122

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
AFOSR/PKC
801 N. Randolph St. Room 732
Arlington, VA 22203-1977

**10. SPONSOR/MONITOR'S ACRONYM(S)**
AFOSR

**11. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**12. DISTRIBUTION AVAILABILITY STATEMENT**
DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH (AFOSR)
NOTICE OF TRANSMITTAL DTIC. THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLIC RELEASE LAW AFR 190-12. DISTRIBUTION IS UNLIMITED.

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

Two Shepherd Model 89 cesium-137 y-ray irradiators were acquired and installed at Vanderbilt University. Safety inspections were performed and appropriate monitoring equipment was put in place. The sources provide capability for irradiating electronic devices at relatively low dose rates, which is important for understanding important device-level degradation effects, including the Enchanced Low-Dose-Rate Sensitivity (ELDRS) of bipolar integrated circuits and long-term degradation and in-situ annealing of MOS integrated circuits.

**15. SUBJECT TERMS**
Two isotopic irradiators loaded with Cs-137 sources (with a half life of 30.2 years) were acquired.

| 16. SECURITY CLASSIFICATION OF: a. REPORT | b. ABSTRACT | c. THIS PAGE | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| | | | SAR | 18 | Ronald D. Schrimpf |
| | | | | | 19b. TELEPONE NUMBER (*Include area code*) (615) 343-0507 |

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI-Std Z39-18

# Radiation Sources for Total-Dose Testing of Electronics

A Final Report for

Grant # F49620-00-1-0238

Prepared by

Ron Schrimpf
Dan Fleetwood
Bob Weller

Vanderbilt University
Electrical Engineering and Computer Science Department
Nashville, TN 37235

20 February 2002

## I. Abstract

Two Shepherd Model 89 cesium-137 γ-ray irradiators were acquired and installed at Vanderbilt University. Safety inspections were performed and appropriate monitoring equipment was put in place. The sources provide capability for irradiating electronic devices at relatively low dose rates, which is important for understanding important device-level degradation effects, including the Enhanced Low-Dose-Rate Sensitivity (ELDRS) of bipolar integrated circuits and long-term degradation and in-situ annealing of MOS integrated circuits.

## II. Introduction

To accurately assess and ensure the radiation hardness of electronics in natural and military space environments, one must be able to perform laboratory irradiation tests that adequately simulate both the dose rate and the energy of the radiation that will be received in applications of interest. Prior to acquisition of the irradiators through this program, the only radiation source available at the Vanderbilt School of Engineering was a 10-keV x-ray irradiator. The dose rate of this source only goes down to about 20 rad(Si)/s, which is 4-5 orders of magnitude higher than the dose rate in the natural space environment. In addition, the energy of the ionizing radiation from this source is more than a factor of 100 lower than that of the > 1 MeV electrons and protons that deliver the total dose in a space environment. While correlations in energy and dose rate between the 10-keV x-ray irradiator and the space environment have been developed for a limited number of devices (most notably MOS), the nature of this correlation differs for differing materials, and cannot be generalized for other device types. Hence, existing standard military and commercial radiation test methods (e.g., MIL-STD 883, Test Method 1019, or ASTM Method F-1892) do not generally allow the use of a 10-keV x-ray irradiator for qualification of electronics for use in space. In addition, the dependence of the radiation responses of new semiconductor materials remains to be characterized at different energies and dose rates, but past studies suggest that energy and dose rate dependencies are generally expected for radiation response, and these can often be quite strong.

## III. Equipment

Two isotopic irradiators loaded with Cs-137 sources (with a half life of 30.2 years) were acquired. The energy of the primary γ line is 0.51 MeV, which is a much better match to the space environment than is a 10-keV X-ray source. One of the irradiators is loaded with ~130 Ci of Cs-137, to provide a maximum dose rate of ~ 0.1 rad(Si)/s, and the other is loaded with ~40 Ci of Cs-137, to provide a maximum dose rate of 0.03 rad(Si)/s. This dose rate range is a reasonable match to some military space radiation environments, the environment associated with periods immediately after massive solar flares or coronal mass ejections, as well as the usual low-dose-rate conditions of the natural space environment, in which only a few 10's or 100's of rad(Si) are received by electronics in a day. The difference in dose rates of these sources will facilitate studies of materials that are very sensitive to the dose rate of the irradiation, e.g., linear bipolar or MOS electronics, or new materials with low-dose-rate sensitivities that will inevitably be discovered in the future.

Each irradiator has two cesium-137 sources to allow different dose rate ranges. The activity levels for each source as of 01/01/01 were:

<u>Irradiator 1</u>
20 mCi
40 Ci

<u>Irradiator 2</u>
130 mCi
130 Ci

The equipment listed in Table 1 was acquired through this DURIP grant. In addition, expenses associated with installation were also paid for through this grant. Note that the cost of the irradiators was slightly less than originally budgeted.

These are self-contained irradiators and each is a Shepherd Model 89. The sources are contained in 1 rod in each irradiator. The rod resides in a lead-lined pig and is raised out of the pig for test exposures. The exposure chambers are also lead-lined so that there is minimum exposure outside of the irradiators. The irradiator requires a key to operate, additional keys to unlock the doors, and has interlocks that prevent source doors from being opened during testing.

A digital area monitor was purchased from Ludlum Measurements, Inc. and an ion chamber was purchased from Inovision Radiation Measurements, LLC.

## III. Operating Procedures

A detailed set of operating procedures was developed using a similar document in use at Sandia National Laboratories as a template. A copy of the Operating Procedure document is attached as an Appendix to this report.

Table 1

**Center #4-22-421-4122 - Eqiupment Purchased**

| Date | Equipment (Description) | Total Cost |
|---|---|---|
| 1/15/01 | Vanderbilt Plant Ops - rekey doors for equipment delivery | $ 75.00 |
| 1/15/01 | Vanderbilt Plant Ops - rekey doors for equipment delivery | $ 30.00 |
| 1/16/01 | Vanderbilt Plant Ops - equipment delivery assistance | $ 897.00 |
| 1/17/01 | Vanderbilt Plant Ops - equipment delivery assistance | $ 537.86 |
| 1/24/01 | J. L. Shepherd -<br>Model 89-30 Self-Contained Irradiation Facility<br>Model 89-130 Self-Contained Irradiation Facility<br>Model 89 Installation and Training<br>Estimated Shipping Costs | $ 146,605.00 |
| 2/15/01 | J. L. Shepherd - freight charges | $ 1,033.68 |
| 3/10/01 | J. L. Shepherd - freight charges | $ 548.47 |
| 4/16/01 | Ludlum Measurements, Inc.<br>Digital Area Monitor - Model 375/2 - Display mR/hr | $ 1,842.31 |
| 6/30/01 | Vanderbilt Plant Ops - new cylinder on door lock/10 keys | $ 39.00 |
| 7/9/01 | Inovision Radiation Measurements, LLC<br>The following items were purchased as a group:<br>Electrometer<br>Battery Charger 12V, 1A<br>33CC Ion Chamber, Triax<br>Equilibrium cap, 2 MEV.<br>Total cost for all was $5,540.00, plus freight | $ 2,892.77 |
| 9/21/01 | Inovision Radiation Measurements, LLC - credit on wrong part | $ (803.18) |
| | TOTAL | $ 153,697.91 |
| | Total Funding Awarded | $ 154,450.00 |
| | Balance not spent | $ 752.09 |

## IV. Status

The irradiators were acquired and installed as planned. The installation of the sources was monitored by Vanderbilt University and State of Tennessee personnel. We have received approval for the installation and operating procedures from the Vanderbilt University Radiation Safety Committee and plan to begin use of the sources in Spring-Summer 2002.

## V. Conclusion

The irradiators and monitoring equipment have been installed. Operating procedures have been developed and approved. The sources are ready for use and we plan to conduct the first experiments in them in the Spring-Summer 2002 timeframe.

# OPERATING PROCEDURE

Title: Shepherd Model 89 Irradiators

Location: Olin Hall, Room 010

SIGNATURES of assigned EECS faculty members:

______________________________ Date: __________
D. M. Fleetwood, EECS

______________________________ Date: __________
R. D. Schrimpf, EECS

______________________________ Date: __________
R. A. Weller, EECS

Note: This procedure is adapted for Vanderbilt University use, based an OP developed by Leonard C. Riewe of Sandia National Laboratories, with permission of the author.

TABLE OF CONTENTS

OPERATING PROCEDURE
SHEPHERD MODEL 89 IRRADIATOR

1.0 PURPOSE

This Operating Procedure (OP) provides instructions and guidance for conducting operations for either of the two Shepherd Model 89 cesium 137 irradiators located in Olin Hall, Room 010. The operation performed in the Shepherd 89 irradiator is total dose testing of semiconductor components and other microelectronic or photonic materials. This procedure is intended to provide detailed procedures on the operation of the Shepherd Model 89 irradiator.

2.0 DEFINITIONS

2.1 ALARA (As Low As Reasonably Achievable)- An approach to radiological protection that controls or manages personnel radiation dose equivalents as low as social, technical, economic, practical, and public policy considerations permit.

2.2 Radiation Laboratory - A facility where radiation testing is performed on components or materials using a machine that produces ionizing radiation.

2.3 Radiation Worker -An occupational worker who operates radiation-producing devices or works with radioactive materials.

2.4 "Shall" - The word *shall* is used in conjunction with the minimum requirements and means that the action described is mandatory.

2.5 "Should" - The word *should* is used in conjunction with good practice and means that the action indicated is recommended.

3.0 RESPONSIBILITIES

3.1 Operators shall:

3.1.1 read, understand, and sign Section 10.0 of this document).

3.1.2 ensure that they have received the proper training as described in Section 4.0.

3.1.3 ensure that they, and any visitors to the laboratory that they are responsible for, have a personnel dosimeter issued by Vanderbilt University's radiation safety department.

3.1.4 have the responsibility and authority to stop or prevent initiation of any job or work activity involving radiation, if continued performance of the work would result in the violation of radiological protection requirements, programs, or procedures, or would otherwise endanger the safety of personnel.

3.1.5 never bypass, modify, or disable radiation alarms or entry or access control systems.

3.1.6 be responsible for maintaining workplace shielded radiation levels ALARA through the use of good housekeeping and other good operating practices.

3.1.7 post "Cell in Use" sign when appropriate.

3.2 An EECS faculty committee consisting of Professors Weller, Schrimpf, and Fleetwood shall:

3.2.1 determine the personnel in their organization who will operate the sources, ensure that they receive the training requirements as identified in section 4.0, and approve these personnel as authorized users.

3.2.2 be responsible for verifying that all safety, personnel, and equipment requirements have been satisfied.

3.2.3 verify by periodic inspection and discussion at semi-annual safety meetings that these procedures are being utilized.

3.2.4 designate a senior operator, or operators (normally a post-doctoral associate) to oversee day-to-day operations of the radiation sources

3.3 Visitors to Olin 010 must possess a personnel dosimeter issued by Vanderbilt University. Visitors will be accompanied by an authorized operator, as defined in Section 3.1, at all items while in the controlled area.

## 4.0 TRAINING

Shepherd 89 Operator Training shall be administered by the EECS faculty committee before any new user is authorized to operate the cells. This requirement is in addition to any general training required by Vanderbilt University for working with radioscopic sources or radiation generating machines.

5.0 SAFETY NOTES

5.1 Before operating the Shepherd 89 irradiator, ensure that you have the proper training and authorization, and you are wearing your personnel dosimeter.

5.2 Irradiators can be dangerous to both the operator and persons in the immediate vicinity unless safety procedures are strictly observed. Exposure to high levels of gamma radiation may cause injury or death.

5.3 Personnel exposures shall be maintained ALARA (As Low As Reasonably Achievable).

5.4 Before closing the door, ensure that all cables and operator fingers are not in the vicinity of the pinch points. If the door is closed before the operator's hand is completely removed from the cavity, the hand and/or fingers will be crushed.

5.5 Do not operator the sources in any other location or operating configuration other than those approved by Radiation Safety. Shielding around the sources shall never be tampered with.

6.0 EQUIPMENT AND MATERIALS

6.1 Equipment

6.1.1 The Shepherd Model 89 cesium 137 irradiator is a self-contained irradiator. There are two irradiators in the radiation laboratory. The Irradiators and their respective sources are as follows

#1. 20 mCi as of 01/01/01
40 Ci as of 01/01/01

#2. 130 mCi as of 01/01/01
130 Ci as of 01/01/01

The sources are contained in 1 rod in each irradiator. The rod resides in a lead lined pig and are raised out of the pig for test exposures. The exposure chambers are also lead lined so that there is minimum exposure outside of the irradiator. The irradiator requires a key to operate, additional keys to unlock the doors, and has interlocks that prevent source doors from being opened during testing and vice versa. The irradiator shall have annual preventative maintenance and one point calibration check. Testing is performed using TLDs so detailed calibration is not required.

6.1.2 The radiation monitoring equipment used is a Model 375-2 Digital Area Monitor. The monitor must be present and functional in order to perform any operations in the irradiators.

6.2 Materials

6.2.1 Radioactive materials - The Shepherd 89 irradiator contains cesium 137, a radioactive isotope. As outlined in 8.1.1, the cesium is inaccessible to any personnel during normal operation of the irradiator.

6.2.2 Toxic materials - Lead is used for shielding during testing in the irradiator. Operators should either wear gloves when handling lead or wash their hands immediately after handling lead.

## 7.0 OPERATING PROCEDURE

### 7.1 General Instructions

7.1.1 <u>ALARA</u> (As Low As Reasonably Achievable) Policy

7.1.1.1 Operators are discouraged from remaining in the radiation laboratory when their test does not require constant monitoring.

7.1.1.2 All unattended experiments must have the radiation source door secured with a lock. The door lock keys shall be secured in the lockbox. The custodian of the lockbox will be a trained, senior operator designated by Professors Schrimpf, Weller, and Fleetwood.

7.1.2 <u>Initial Conditions</u>

7.1.2.1 **<u>DO NOT</u>** remove any parts of the irradiator shielding.

7.1.2.2 **<u>DO NOT</u>** remove or bypass the electrical radiation interlock system.

7.1.2.3 All keys shall be stored when the equipment is not in use. The irradiator door key shall be secured in the lockbox during unattended experiments.

7.1.2.4 Verify that a radiation detector is mounted on the laboratory wall. Check the monitor to verify that it is plugged in and that the reading is above one. Typically the monitor should read approximately 2 mr/hr. If in doubt as to the operation of the detector or monitor, do

not operate irradiator, do not begin any exposure until senior operating personnel have inspected the source area and the monitor.

7.1.2.5 Prior to each use of the source, the interlock must be tested as follows:

a. Secure the door with a lock, then raise the source.

b. Push the door interlock button several times.

c. If a loud click is audible, then the interlock has failed. Lower the source, notify a senior operator, who will contact Vanderbilt University radiation safety and the manufacturer, tag the irradiator with an "Out of Service" tag, and return the source keys to the lock box.

d. If loud clicks are not audible, then proceed with exposures.

## 7.2 Operations

### 7.2.1 Exposures

7.2.1.1 Electronic Timer and Control Panel Operation

7.2.1.1.1 Turn the key operated power switch on the control panel to the "ON" position. A panel light will indicate that the power is on.

7.2.1.1.2 Place the mode selector switch to "Manual" or "Preset" time.

7.2.1.1.3 To preset time on the electronic timer, press buttons above and below the digits on the preset timer to preset the time desired. Press the "Reset" button.

7.2.1.1.4 On the control panel, select the correct source on the selector switch.

7.2.1.1.5 To raise the source, ensure that all irradiator doors are closed, then press the red "irradiate" position immediately.

7.2.1.1.6 The raised source may be returned to the "off" position by the following methods:

A. Completion of the preset exposure.

B. Pressing the green "OFF" button which overrides the preset timer.

C. Activation of any interlocks or removal of power as discussed under emergency shutdown. These procedures should not be used under normal operations.

7.2.1.1.7 After completion of any exposure, it is necessary to press the "Reset" button before another exposure is initiated. Pressing this button will automatically reset the preset time previously selected. If this is not done, the source cannot be raised.

7.2.1.1.8 In operation, the timer starts at 000 and returns to the time preset after the exposure is completed. The display shows the elapsed time on the exposure in minutes, and tenths of minutes.

7.2.1.1.9 Operate the attenuators by sliding them in a horizontal direction using the handles provided. With the attenuators in the "Attenuate" position, they are pushed fully in toward the center of the calibrator. With the attenuators in the "Open" position, they are pulled out against he positioning stops provided. DO NOT attempt to twist or turn the operating handles, since this may damage the attenuators. The attenuators should be closed (pushed in) when the irradiator door is open.

7.2.1.2 Irradiator Door

7.2.1.2.1 The irradiator must be powered on for operation of doors. To open the door, remove the lock from the door latch. With both sources in the "off" position, press the momentary pushbutton switch on the side of the interlock box mounted adjacent to the left side of the door and pull on latch handle. To close the door, shut door until it latches. Replace lock on door after closing.

7.2.1.2.2 Before closing the door, ensure that all cables and operator fingers are not in the vicinity of the pinch points. If the door is closed before the operator's hand is completely removed form the cavity, the hand and/or fingers will be crushed.

7.2.1.2.3 The door must be secured with a lock and the key secured at all times other than during test setup.

7.2.1.3 Experiment Mounting Cart

7.2.1.3.1 An experiment mounting cart is provided which rolls on tracks in the irradiation tunnel.

7.2.1.3.2 The cart is driven in the tunnel by means of a chain drive operated by a black operating handle located slightly below and behind the hinged side of the end door. If the chain becomes disconnected from the handle, the operator may complete the test by manual operation of the experiment cart. Notify a senior cell operator if this is malfunctioning.

7.2.1.3.3 There is a distance indicator adjacent to the black operating handle which reads the distance from the source rods in millimeters. Check calibration of cart when using it.

7.2.1.3.4 An access plug for running cables to experiments is located beneath the irradiator. To use, place experiment cables or wires through serpentine plug, and replace plug in irradiator. The plug ports on the rear of the irradiator are not to be used for cable access without approval and survey by Vanderbilt University radiation safety.

7.2.2 <u>Maintenance</u>

7.2.2.1 This irradiator shall be installed, relocated, and dismantled by the manufacturer with the concurrence of Vanderbilt University radiation safety.

7.2.2.2 Only authorized maintenance personnel may attempt any repairs or adjustments. Operators shall notify a senior operator or one of the assigned EECS faculty members if the irradiator equipment malfunctions.

7.2.2.3 A senior operator should tighten the set screws for the sprockets and operating knob at 6 month intervals and whenever the table does not maintain adjustment.

7.2.2.4 Maintenance personnel should calibrate the source to experiment mounting table distance at 6 month intervals.

7.2.2.5 **DO NOT** place any lubricant on the source rod or the tubes through which it passes. This will cause a malfunction and/or damage to the irradiator.

7.2.2.6 Maintenance personnel shall not perform routine electrical service to any irradiator interlocks. This shall only be performed by the manufacturer.

7.2.3 Status Indicators

7.2.3.1 The position of the sources is indicated by lights on the top of the calibrator (tower). The green light will glow when both sources are in the "off" position. Individual red lights glow when either of the sources are in the "irradiate" position.

7.2.3.2 An "Out Of Service" tag on the source indicates a malfunction of the source. No operations are permitted until Vanderbilt University radiation safety removes the tag.

7.2.3.3 If the radiation alarm is activated, it is an indication high radiation levels in the laboratory. In such an instance, follow the procedures outlined in 7.3.2 below.

7.2.4 Operating Log. The operator is responsible for filling out the operator log indicating the user, the dates, the start/stop times for each irradiation, and a brief comment about the purpose of the experiment.

7.3 Emergency Procedures

7.3.1 Source Malfunction

7.3.1.1 If the sources do not raise smoothly and easily or if the sources do not return smoothly to the "off" position following exposure, lower sources and lock pin, lock the irradiator door, place an "Out Of Service" tag on the irradiator and contact a senior operator or an assigned EECS faculty member immediately. They will check the

sources and immediately notify Vanderbilt University radiation safety, if a problem is confirmed. Give the keys to a senior operator or assigned faculty member.

7.3.1.2 If it is possible to open any irradiator door without pressing the door release button, immediately close and lock the door, place an "Out Of Service" tag on the irradiator, and contact Vanderbilt University radiation safety. Give the irradiator keys to a senior operator or assigned faculty member.

7.3.1.3 If it is impossible to raise the sources with the door closed or to open the door with the sources in the "off" position, immediately place an "Out Of Service" tag on the irradiator and contact a senior operator.

7.3.2 **Radiation Emergency** - If the radiation alarm sounds in the laboratory, take the following actions

7.3.2.1 Perform an emergency shut-down of the radiation source only if the reason for the alarm is not immediately correctable (ex. source door open, or obvious alarm malfunction - since there are two alarms in the room, this should be easily verified).

7.3.2.2 If the emergency shut-down is successful, notify Vanderbilt University radiation safety immediately. **DO NOT** attempt to continue operations. Lock the source door and give keys to an assigned EECS faculty member.

7.3.2.3 In the unlikely event that the radiation emergency cannot be assessed immediately or if the emergency shut-down is not successful on the first attempt, evacuate the room immediately and close the door, notify occupants of adjacent laboratories and in the Chemical Engineering office that is directly upstairs, and then evacuate the building. Then immediately call "911" from another building and specify the nature of the emergency. Notify one of the emergency response team members on the scene as to the nature of the emergency. Notify Vanderbilt University radiation safety.

7.3.3 Emergency Shut-Down - Removing power from the Shepherd 89 irradiator will NOT cause the source rod to drop to the "off" position. The rod must be manually lowered as outlined in 7.2.1. Removing power will turn

off the interlocks. The interlocks should fail "safe", which means that when power is removed, the door cannot be opened.

## 8.0 AUTHORIZED PERSONNEL

The following personnel have read and understood this OP and are authorized to operate the equipment described above.

The designated senior operator as of 1/1/01 is Bo K. Choi.

| NAME (printed) | SIGNATURE | DATE |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |